CLAIRBOIS'
NAVAL ARCHITECTURE
BY
CAPT^{N}. STRANGE.

46.

499.

ELEMENTS

OF

NAVAL ARCHITECTURE:

BEING

A TRANSLATION OF THE THIRD PART

OF

A WORK ENTITLED

"TRAITÉ ÉLÉMENTAIRE

DE LA CONSTRUCTION DES VAISSEAUX,"

PAR

M. VIAL DE CLAIRBOIS.

BY

J. N. STRANGE,

COMMANDER, R. N.

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TO

THE RIGHT HON. SIR GEO. COCKBURN, G.C.B.,

ADMIRAL OF THE RED,

THIS VOLUME

IS,

BY PERMISSION,

RESPECTFULLY DEDICATED

BY HIS

OBEDIENT HUMBLE SERVANT,

THE TRANSLATOR.

PREFACE.

The name of M. Vial de Clairbois is too well known, in connection with the subject of Naval Architecture, to require any formal introduction. He translated Chapman's valuable work into French, was a chief contributor to the "Dictionnaire de Marine," and in 1787 published the Treatise, the third and last part of which is the original of the present translation.

The work in question was written for the use of the French naval students, in conformity with the express desire of the French Minister of Marine, as M. Clairbois states in his Preface. The first and second parts treat entirely of the shipwrights' department of the subject, and are not, therefore, of great importance to those whom I chiefly wish to serve by this publication, viz. my brother officers, especially those of junior standing. Moreover, we have some recent treatises of the kind by competent authorities in this country, containing all important improvements since M. Clairbois' time. I felt, therefore, that the third part, "On the Theory of

Naval Architecture," was that which might be most useful to the class I have mentioned.

The best works in English on the subject are "Inman's Translation of Chapman," and "Mr. Creuse's Treatise." But the former is rarely to be met with; and the single copy I could, after much search, obtain, was deficient in some of the plates; and even were it less scarce, its price is so high as to deter any but those who intend to make the science their profession, or who take a more than ordinary interest in it, from becoming purchasers. Mr. Creuse's work, which was written for the Encyclopædia Britannica, is a most valuable one of its kind, and accomplishes the object for which it was written; but it is deficient in that which is most essential to a regular student; viz. an example of the calculations of "Displacement" in detail. My own experience of this want first suggested to me the idea of publication. Having met with Clairbois' treatise, which seemed exactly adapted to my wants, I determined to translate it for my own use. In the course of doing so, I found, by conversation with professional men, that it was v ery little known, and more than one friend advised me to print my translation. I was induced to adopt the suggestion, in the hope of adding to the scanty materials of solid knowledge at present possessed;

and with the further intention of offering some aid to the judgment of my brother officers, whose opinions must always exercise a powerful influence on this branch of science.

I am aware that Clairbois' method of calculating the Displacement, as illustrated in this Treatise, differs from that recommended by Chapman, and that the latter is the more approved one; but the difference between their results, (except in vessels of very extraordinary construction) is so slight, as scarcely to be worth notice.

The translation is as literal as possible; and I thought it advisable, considering my own inexperience, not to substitute the English for the French scale of weights and measures, as the operation would have involved an entirely new calculation, which might not have been free from mistakes. I content myself, therefore, with stating the difference between the two scales; which is as follows:—

	No. of lbs. to a cubic foot of sea water.	No. of lbs. to a ton.
English	64.55	2240
French	72	2000

The French foot measures 13·11 in. English; and the fractional measurement throughout this treatise is in 12ths of inches, instead of 10ths.

The Plates are copied from the original, with the exception of Plate 3, which is my own; and which

I have introduced to illustrate some parts of the calculation, that must appear complicated to those who are not familiar with the operation. Plates 1, 2, and 4, are on a reduced scale two-thirds of the original.

I cannot conclude without acknowledging the great assistance I have derived in this work from the "Naval and Military Technical Dictionary," by Captain Burn, R.A., a book of reference to which I never applied in vain.

J. N. STRANGE.

Portsmouth,
October, 1845.

ELEMENTS

OF

NAVAL ARCHITECTURE.

On the Theory of Naval Architecture.

THE Theory of Naval Architecture is entirely founded on Hydrostatic and Hydrodynamic principles. The first of these sciences treats of the equilibrium, either between fluids of different kinds, or between solid bodies and fluids. That which concerns us most in naval architecture is the equilibrium between the floating body or ship, and the water upon which it floats: the working of pumps, which is indirectly connected with the construction of ships, is founded on the equilibrium between air and water.

The science of Hydrodynamics also treats of the equilibrium between fluids, or between solids and fluids; but it is in reference to their motion and resistance. The ship is moved by the wind because some of her parts are so disposed as to participate in the motion of the air: on the other hand, the part which is immersed in the water obeys the condition of that fluid, which is ordinarily stationary: and thus the motion is resisted. The effects of the moving and resisting forces combine, and a certain

progressive motion in a certain direction results from them, more or less considerable in proportion as the form of the body is favourable to such a motion.

In the first section of this treatise we will speak of the body at rest. In the second we must confine ourselves to a mere statement of the problem; for, in Hydrodynamics, our knowledge of first causes is not sufficiently accurate to lead us to satisfactory results.

SECTION FIRST.

OF FLOATING BODIES, OR SHIPS, AT REST.

A floating body is one which, tending by its gravity to sink into the fluid in which it is partly immersed, and by the resultant of the pressure of that fluid upon its immersed part, to rise, remains in equilibrio between these two forces. Floating bodies immerse a part of their volume in the water: this part, or the quantity of water which it displaces, is called the "displacement" of the body; and the weight of the floating body is equal to that of the fluid displaced: that is to say, to the weight of a volume of the fluid equal to that of the immersed part of the body. (See, for the principles and demonstration of this proposition, No. 343 de la Mechanique de Bezout, or page 227. tom. 2nd des Leçons de Physique de l'Abbé Nollet.) Indeed, the fact appears evident on a little reflection. If we lift a floating body out of the water, the void which it created in the water is immediately filled with the fluid. Let us suppose that this water, which has resumed its place, is intercepted by an infinitely thin case, or shell, without weight, which prevents it from communicating directly with the fluid around it: this interception cannot in any way destroy the equilibrium between the particles of the fluid. Suppose again, that we withdraw the water from the case which incloses it, and that this case or shell is sufficiently stiff to

resist the pressure of the external fluid: it is evident that this pressure will tend to raise it to the surface; but that if a weight equal to that of the fluid which has been withdrawn be placed in the shell, the pressure of water upon the shell will be overcome, and the equilibrium be restored. It is the same with floating bodies, and particularly with ships; the frame of the bottom, which is a sort of case, may be supposed itself to be enveloped in the infinitely thin curvilinear shell which we have imagined: and the resistance to her immersion is the effect of the different weights dispersed about her in such a way as to preserve her stability, and keep her in the same position: the sum of these weights is equal to the weight of the volume of water displaced.

The degree of immersion which a ship will have, is a consideration of great importance; and this is especially the case with ships of war. A ship of war, to be efficient, must be able to carry her guns a certain height out of water: if they are too high, the ship will have too much upper works, her stability will be injured, and she will incline to be leewardly: again, if the battery is not high enough, it may sometimes be so buried as to prevent its being used under circumstances of weather when a better constructed opponent may have the full advantage of his:—moreover, when a vessel is designed for a particular purpose, she should possess properties which she might lose by the change of form consequent on a difference in the draught of water. It is known what a vessel fully equipped should weigh (I speak of vessels of war whose weights are definite): the load water line, that is to say the

line which separates the upper works from the immersed part, is marked on the plan: the quantity of water displaced by that immersed part should weigh as much as the ship. In order to determine that it does so, the cubic content of the immersed part is calculated, and the weight found by the relation of the specific gravity of the fluid to its volume. The problem to be solved, therefore, is mainly one of elementary geometry, the bottom being divided into such a number of parts as that the curved lines which bound them may be considered without any sensible error, to be straight; and it is solved by a numerical calculation, called the calculation of the displacement. We shall treat of this in the first chapter.

It is not enough either that a ship should merely be well placed on the water; but she must have stability in that position as well. This stability in bodies at rest, that is, without progressive motion, but subject to the effects of the agitation of the sea, and local alterations of weights on board, will afford matter for the second chapter.

CHAPTER I.

On the Displacement.

A SHIP of 74 guns, such as the one that has been made use of for our explanations, weighs, when fully equipped, at least 2,800 tons: we must reckon in the present instance, upon 3,000: it is necessary, therefore, that her bottom, or that part of her below the water line $l f s$ (Pl. 2. fig. 1.) should displace a volume of water equal to 2,800 or 3,000 tons; that is to say, that its solid content should be made up of as many cubic feet as will equal the ratio between 72lbs, and from 2,800 to 3,000 tons, or from 5,600,000 to 6,000,000lbs. because a cubic foot of salt water weighs about 72lbs. On finding the contents of this immersed part then, and multiplying the number of cubic feet so formed by 72, it will be seen whether the product amounts to 5,600,000 or 6,000,000lbs.; if it should be less, the vessel would not displace enough; and she could not carry her guns five feet out of water, because she would immerse herself into the water until she did displace that quantity: in that case, her dimensions below the load-water line must be increased: i. e. her bottom must be made fuller before any further steps are taken.

I.

Method of finding the solid content of the immersed part.

Pl. 2. Fig. 1. & Pl. 3. Fig. 1. In order to arrive at the solid content required, the bottom must be divided into several divisions, or slices, of

equal thickness; in the present instance it is divided into six as 1*f*ss′, 2*f*. 2*f*s′s″ 3*f*. &c. It is further subdivided by the vertical sections *mm*′, 11′, 22′, &c. 77′, MM′, 11′, &c. VI VI′. These vertical sections or frames are at equal distances; so that they cut up the ship's bottom into as many pieces of equal width. There is an exception to this in the ship before us, in which the distance between the two dead flat sections MM′ and *mm*′ is greater than between the others. This is not usual, and for the present we will take no notice of it, but return to it hereafter. The seventh section of the fore body VII VII′, and the false section *fc fc*′ of the after body being also at unequal distances from their neighbours, the lines 7″ 7‴, VII″ VII‴ are drawn at the common distance of the frames from each other, solely to facilitate the calculation of the displacement. Pl. 2. Fig. 1. & Pl. 3. Fig. 1.

In this way we have the part of the hull contained between the horizontal sections or water lines 1*f*s, 7*f*s‴ and the vertical sections 7″ 7‴, VII″ VII‴ divided into a great number of prisms, of equal thickness and width, and differing only in length. These lengths are actually the breadths of the hull at each of their edges. For instance in TT′, *tt*′ the projection of the edges of the prism, whose vertical sections are TT′, *tt*′ its lengths AT, AT′, *at*, *at*′ (Pl. 1.) are the breadths of the vessel at the intersection of the second and third horizontal sections 2*f*s′, 3*f*s″ with the vertical sections 66′, 77′.

To arrive at the solid content of each of these prisms, it will be sufficiently near the truth to multiply their common thickness TT′ *tt*′ by one-fourth the sum of their

Pl. 2. Fig. 1. & Pl. 3. Fig. 1. four edges, or, which is the same thing, by the sum of the fourth of each: this is what is called the mean length.

Thus, to find the solid content of the part under consideration, we must compute the sum of the mean lengths of the prisms which compose it; or, which is the same thing, add together the fourths of all the ordinates of the sections both vertical and horizontal, and multiply the sum by the common area of the ends of the prisms.

The following considerations assist materially in simplifying the operation.

First. All the interior prisms have each of their four edges common to four prisms. The edge, of which T is the projection, is common to the prism TT', *tt'*, to that one abaft it marked Y'*t*, and to the two immediately above XT and YT, &c. It is of course understood that by interior prisms, we mean those, none of whose planes are identical with the upper or lower horizontal, the foremost or aftermost vertical sections, which bound the part whose solid content is the subject of investigation.

Secondly. The edges which appear in those sections (viz. the upper and lower horizontal, and the foremost and aftermost vertical sections) are only common to two prisms: again, the extreme edges of these sections only belong to one. The edge X belongs only to the prism XT: those marked Y and Y' are common, the first to the two prisms XT and YT', the other to XT and Y'*t*, &c.

It follows from this that, to find the solid content of the part of the ship comprised within these sections, we must *add together the fourths of the extreme, and the halves of the other ordinates of the upper and lower horizontal*

sections; and the halves of the extreme, and the whole of the other ordinates of the intermediate horizontal sections; and multiply the sum by the common area of the prisms, or the rectangle TT′ *tt′*.* Pl. 2. Fig. 1. & Pl. 3. Fig. 1.

It is customary to trace these sections as they are seen in Pl. 2. fig. 2: this figure represents the seven sections or planes, 1*fs*, 2*fs′*, &c. 7*fs‴*, (fig. 2.) which define the six divisions composing the part of the hull, whose solid

* The rule used by Chapman differs from this, in that it treats all the sections actually as curvilinear planes. The following extract from Hymer's Integral Calculus, the figure for which will be found as No. 3, in Plate 5, will explain this method.

"Let it be required to find the area PNKU included between the ordinates PN, KU; divide their distance NK into an *odd* number $(n-1)$ of parts, each $= h$, and call the corresponding ordinates $a_1\ a_2\ a_3$ &c. Through the extremities of the three first describe a parabola PQR having its axis parallel to the ordinates of the curve; draw the chord PR which will be bisected in V by the intermediate ordinate, and will be parallel to the tangent of the parabola at Q, therefore as the area of parabolic segment $= \frac{2}{3}$ circumscribing parallelogram, area PQRV $= \frac{2}{3}$ QV.NL $= \frac{4h}{3}$ $\left\{a_2 - \frac{1}{2}\left(a_1 + a_3\right)\right\}$ and area of trapezium PRLN $= 2h \dfrac{a_1 + a_3}{2}$

therefore, the whole area PQRLN $= h \left\{a_1 + a_3 + \frac{4}{3} a_2 - \frac{2}{3}\left(a_1 + a_3\right)\right\}$

$$= \frac{h}{3}\left(a_1 + 4a_2 + a_3\right)$$

similarly describing a parabola through the points R,S,T,

$$\text{area RTML} = \frac{h}{3}\left(a_3 + 4a_4 + a_5\right) \text{ \&c.}$$

Hence by addition the whole curvilinear area

$$\text{PNKU} = \frac{h}{3}\left(a_1 + a_n + 4a_2 + 2a_3 + 4a_4 + 2a_5 + \ldots 4a_{n-1}\right)$$

Hence the Rule. Add the first and last ordinates to four times the sum of the even, and twice the sum of the odd ones, and multiply by $\frac{1}{3}$ the common distance of the ordinates."

This gives the area of any one section; the rest of the calculation is the same as that of Clairbois.—Ed.

contents we are in search of. They are curves, the line of whose abscisses is the line *p* P, (fig. 2), and whose ordinates are the projections of the vertical planes; 70, 7′*f*1 is the ordinate of the first horizontal section at 7 abaft: 70, 7′*f*2, a like ordinate of the second section, &c. These are the ordinates with which we have to deal upon the principles stated above. The form of this calculation on the next page, will make it more clear.

Form I.—*Calculation of Displacement.*

Ordinates.	1st Sect.	2nd Sect.	3rd Sect.	4th Sect.	5th Sect.	6th Sect.	7th Sect.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
7″	4 2	1 3.6	8	5	4.6	4.6	3.6
7	15 8	11 7	5 9	2 7	1 3.6	7	3.6
6	18 1.9	16 3	12 9	8 0.3	4 1	1 9.6	6.6
5	19 6	18 3.6	16 3.9	13	8 6.6	4	1 1
4	20 6	19 6.9	18 3.3	16	12 8	7 7	2 2
3	21 4.6	20 7.6	19 5.9	17 9.6	15 3.3	11 6	3 9.6
2	21 10.6	21 3.6	20 4.6	18 11	16 11	13 11.6	6 1.6
1	22 1.6	21 7.9	20 11.6	19 6	17 10	15 4	9 7
m.	22 2.6	21 10.6	21 2.6	20	18 4.6	16 0.6	11 9
M.	22 2.6	21 11	21 2.6	20	18 4.6	16	11 9
I.	22 2.6	21 9.3	21	19 8	17 10	15 3.9	9 1.3
II.	22 2	21 7.6	20 7.9	19 0.6	16 11	14 1.6	5 4.6
III.	22	21 2.6	19 10	17 10	15 4.3	11 7	2 11
IV.	21 2	20 1	18 4.3	15 11	12 6.6	8 1	1 8.6
V.	19 7	18	15 8	12 7	8 9.6	4 5.6	11.6
VI.	15 10	13 9.6	10 8.6	7 1	3 10	1 6	5.6
VII.″	6 9	4 5	2 1	4	4.6	4.6	3.6
	317 5.9	295 2.9	265 3.3	228 8.3	189 4.6	142 7.3	68 2.3
	9 11	8 6	7 1	6 4.6	6 4.6	6 4.6	6 4.6
	327 4.9	303 8.9	272 4.3	235 0.9	195 9	148 11.9	74 6.9
	6 6	303 8 9	272 4.3	235 0.9	195 9	148 11.9	8
	321 4.3	607 5.6	544 8.6	470 1.6	391 6	297 11.6	73 10.9
	600 9	6 8.6	3 7	1 6	1 6	1 6	
	541 1.6						V.
	468 7.6	600 9	541 1.6	468 7.6	390	296 5.6	
	390						73 10 9
	296 5.6	10 1	MC.	B.	AR.	AV.	×10 1
	73 10.9	×3					
			22 2.6	7	4 2	6 9	=745 1.4
	2692 2.6	=30 3	21 10.6	6	1 3.6	4 5	×1 10.6
	×30. 3		21 10.6	6	1 3.6	4 5	
		3	21 2.6	5	8	2 1	1397 1.1½
	=81439 3.7½	×1 11	21 2.6	5	8	2 1	
MC. . .	1345 6		20	4.6	5	4.6	Q.
AR. . .	65 11.5¼	=5 9	20	4.6	5	4.6	
AV. . .	165 8.6		18 4.6	4.6	4 6	4.6	200
V. . .	1397 1.1½	2 5	18 4.6	4.6	4.6	4.6	×1 ¼
Q. . .	375	4.6	16 0.6	4.6	4 6	4.6	
			16 0.6	4.6	4.6	4.6	=250
	84788 6.8	2 9.6	11 9	4.6	3.6	3.6	×1 ½
	×72	×3					
			228 11.6	5 0.6	10 8.6	22 3.6	=375
	=6104776	=8 4.6	5 0.6		5 6.6	5 0.6	
	tons. lbs.	3 8	234		15 0	27 4	
	=3052 776	4.6	×5 9		×8 4.6	×12 1.6	
		=4 0.6	1345 6		=131 10.10½	=331 5	
		×3			× ½	× ½	
		=12 1.6			=65 11.5¼	=165 8.6	
		1 6					
		4.6					
		1 10 6					

Pl. 2. Fig. 2. & Pl. 3. Fig. 1. This form contains seven columns for the seven horizontal sections or water lines, in each of which are set down the seventeen ordinates of these sections—4 ft. 2 in. is the first ordinate $7''0\ 7'''\int 1$ of the first section—15 ft. 8 in. is the second ordinate $70\ 7'\int 1$ of this same section, &c. The first ordinate of the second section $7''0\ 7''\int 2$ is $\overset{\text{ft.}}{1}\ \overset{\text{in.}}{3.6}$ set down at the top of the second column; the second of this same second column $70\ 7'\int 2$ is 11 ft. 7 in. &c. This is enough to shew the principle of the form.

As there are reasons for not including the thickness of the planking in drafts of ships, an addition must be made to these ordinates on this account. The planking of the ship upon which we are at work may be about seven inches at the upper section; that is, 7 in. must be added to each of the 17 ordinates, which will amount to 9 ft. 11 in., and makes the sum total of these ordinates $\overset{\text{ft.}}{327}\ \overset{\text{in.}}{4.9}$

We have seen by the Rule that half the breadths at the upper section are to be used: these ordinates are actually the half breadths. But only a fourth of the breadths or half the extreme ordinates is to enter into our calculation; so we must deduct from $\overset{\text{ft.}}{327}\ \overset{\text{in.}}{4.9}$ half the said ordinates, including the thickness of plank; that is to say,— $\frac{\overset{\text{ft.}}{4}\ \overset{\text{in.}}{2} + \overset{\text{in.}}{7} + \overset{\text{ft.}}{6}\ \overset{\text{in.}}{9} + \overset{\text{in.}}{7}}{2} = \overset{\text{ft.}}{6}\ \overset{\text{in.}}{0.6}$, and we have for our upper horizontal section $\overset{\text{ft.}}{321}\ \overset{\text{in.}}{4.3}$.

The five succeeding columns contain the ordinates or half breadths of the intermediate horizontal sections: the thickness of plank must first be added to each; viz. 6 in. to the first of these intermediate sections, 5 in. to the second, 4½ in. to the others, which give the respective amounts 8 ft. 6 in., 7 ft. 1 in., &c.

The breadths of the intermediate sections ought to be taken entire, with the exception of their extremes. Having therefore doubled the sum of the ordinates, we have only to deduct from this product the sum of the extreme ordinates, still including the thickness of plank: that is to say, for the second section, or first of the intermediate ones, $\overset{\text{ft.}}{1}\ \overset{\text{in.}}{3.6} + \overset{\text{in.}}{6} + \overset{\text{ft.}}{4}\ \overset{\text{in.}}{5} + \overset{\text{in.}}{6} = \overset{\text{ft.}}{6}\ \overset{\text{in.}}{8.6}$: and the same process for the rest. Pl. 2. Fig. 2. & Pl. 3. Fig. 1.

The seventh section is treated like the first, bearing in mind the thickness of plank, which, there, is only $\overset{\text{in.}}{4.6}$.

Having thus the several sums of the ordinates of each horizontal section, they must be added together, when they will, as is seen, produce a sum total of $\overset{\text{ft.}}{2692}\ \overset{\text{in.}}{2.6}$. It is this quantity which must be multiplied by the area of the rectangle TT′ $t't$ (Fig. 1), which is evidently the product of the distance TT′ between the vertical sections $= \overset{\text{ft.}}{10}\ \overset{\text{in.}}{1}$. multiplied into T$t$, that between the horizontal sections $= \overset{\text{ft.}}{3}$. We have then $\overset{\text{ft.}}{2692}\ \overset{\text{in.}}{2.6}$ to be multiplied into $\overset{\text{ft.}}{30}\ \overset{\text{in.}}{3}$, which gives a product $= \overset{\text{ft.}}{81439}\ \overset{\text{in.}}{3.7\frac{1}{2}}$ cube: at 72 lbs. a cubic foot, this part of the ship's bottom alone will be 5,863,608 lbs. or 2931¼ tons.

We have now clearly disposed of the greater portion of the "bottom;" and have got a general notion of the displacement: but it is not all. There still remain, before the vertical section VII″ VII‴, abaft the one 7″ 7‴, and below the horizontal section 7/s‴ some small pieces to be cubed, which may be considered parabolic. This is a general rule for all vessels; but ours in particular has a

Pl. 2. Fig. 2. & Pl. 3. Fig. 1. piece left between the two dead flat sections a distance of 12 ft., which we have reckoned as $\overset{\text{ft.}}{10}\ \overset{\text{in.}}{1}$, like the other sections, leaving a prismatic solid, having the area of one of the dead flats for its base, and 1 ft. 11 in. for its height, whose displacement is to be found.

Beginning with this piece, let us compute the area of that portion of one of the dead flats, which lies between the upper and lower horizontal sections. Upon the same principle that has guided us before, we have to add together the breadths of the dead flat at the intermediate sections, and the half breadths or simple ordinates at the upper and lower sections: this has been done in the column MC of the Form. These breadths or ordinates are taken from the seven columns of the calculation already gone through, along the line of the dead flats M or *m*. Of course the thickness of plank, viz., $\overset{\text{in.}}{7}$ at the upper section, $\overset{\text{in.}}{6}$ at the second, &c., making in all $\overset{\text{ft}}{5}\ \overset{\text{in.}}{0.6}$ must be added. For the area of the dead flat we have to multiply the quantity $\overset{\text{ft.}}{234}$ by $3 =$ the distance between the sections: and, for the solid contents of the piece in question, we must multiply again by $\overset{\text{ft.}}{1}\ \overset{\text{in.}}{11}$: or (as has been done in the form) multiply $\overset{\text{ft.}}{3}$ by $\overset{\text{ft.}}{1}\ \overset{\text{in.}}{11}$, and then $\overset{\text{ft.}}{234}$ by their product $\overset{\text{ft.}}{5}\ \overset{\text{in.}}{9}$.

The solid content of the small pieee abaft the section $7''\ 7'''$ is obtained by multiplying the area, of which $\sigma\,\sigma\,\sigma$ (Pl. 1.) is the half, by the half of $\overset{\text{ft.}}{2}\ \overset{\text{in.}}{9.6}$, the distance from this section to the rabbet including the thickness of plank. This half distance is used because the piece is

considered as a paraboloid.* To find the area required, Pl. 2. Fig. 2. & Pl. 3. Fig. 1.
we must go through the same process as above for the dead flat, the ordinates being taken from the seven columns at the line 7″ (vide AR): the thickness of plank $\overset{\text{ft.}}{5}\ \overset{\text{in.}}{0.6}$ is in like manner added, and the whole multiplied by $\overset{\text{ft.}}{8}\ \overset{\text{in.}}{4.6}$ = the product of the distance between the ordinates $\overset{\text{ft.}}{3}$ multiplied by the distance $\overset{\text{ft.}}{2}\ \overset{\text{in.}}{9.6}$. We then divide by 2, which gives us the solid content sought.

The section VII″ VII‴ is at a distance of $\overset{\text{ft.}}{4}\ \overset{\text{in.}}{0.6}$ from the outside of the rabbet; and the mode of operation for finding the solid content of the piece before this section, is the same as for that abaft (see col. AV).

The ordinates of the section 7/s‴ are all prepared in the seventh column conveniently for going through the same process as for the small pieces of the fore and after bodies. Only, as they present but half the section, in multiplying the distance $\overset{\text{ft.}}{1}\ \overset{\text{in.}}{10.6}$ from this section to the rabbet of the keel, there is no necessity for dividing by 2: but the quantity $\overset{\text{ft.}}{73}\ \overset{\text{in.}}{10.9}$, the result of the addition of

* The following formulæ will be found useful in calculating the areas and solid contents of several regular shaped planes and solids :—

Area of circle	= circumference × radius.[2]
— Ellipse	= 3.1416 × semimajor axis × semiminor axis.
— Parabola	= $\frac{2}{3}$ circumscribing rectangle.
— Cycloid	= 3 area of generating circle.
Volume of Sphere	= $\frac{2}{3}$ circumscribing cylinder.
— Paraboloid	= $\frac{1}{2}$ circumscribing cylinder
— Cone with circular base	= $\frac{1}{3}$ of a cylinder of the same base and altitude.—Ed.

Pl. 2. Fig. 2. & Pl. 3. Fig. 1. the column, must first be multiplied by 10 ft. 1 in., the distance between the ordinates, in order to get the area of the section.

Besides all these pieces, there are lastly about 200 ft. of stern-post, keel, and stem, 15 in. in width, and 18 in. in depth; which contain 375 cubic feet to be added to the displacement of the ship's bottom.

Adding the respective results of all these calculations to the 81,439 ft. already found as the solid contents of the main portion of the immersed part of the ship, we have a sum total of 84,788 ft. 6.8 in. which, multiplied by 72 and divided by 2000 (= the number of lbs. to a ton) gives the actual displacement of the ship = 3052 tons. 776 lbs.

The supposition that the small pieces of the fore and after bodies, and that towards the floor, are parabolic, is not quite exact; but it is so near the truth that the error may safely be neglected.

II.

Method of finding the solid content of the immersed part in two equal divisions, in order to find the excess of the displacement of the fore body over that of the after.

Ships have necessarily considerable weights at the extremity of the fore body: such as the anchors, the galley, the foremast and bowsprit; an indispensable arrangement, which requires an excess of displacement in the fore body over the after one. We must now satisfy ourselves that there is the necessary difference between these two parts.

For this purpose the length of the hull taken at the load water line is divided into two equal parts. We have found the respective lengths of the several pieces composing the whole immersed part to be as follows. Pl. 2. Fig. 1. & Pl. 3. Fig. 2.

	ft. in.
The little piece abaft 7'' 7'''	2 9.6
From 7'' 7''' to the aftermost dead flat eight distances of 10 1 (ft. in.) each making .	80 8
Between the two dead flats	12 0
From the foremost dead flat to VII'' VII''' distances of 10 1 (ft. in.) each making .	70 7
The little piece before VII'' VII'''	4 0.6
2)	170 1
	85 0.6

The division, therefore, falls between the two dead flats, 1 7 (ft. in.) before the after one: all this is shewn clearly in Form 2.

To find the solid content of each of these parts, we must go to work as we did for the whole body. The nine after ordinates are arranged as the seventeen were in Form 1. They are prepared in the same way (see Form 2) and we have 38,222 9.2 (ft. in.) as the solid content of the principal part between the vertical section 7'' 7''', and the dead flat section *mm'*. To this must be added the small piece abaft 7'' 7''', the value of which is found in AR. (Form 1).

The piece at the fore part of this half of the ship's bottom is a body of prismatic shape, having for its base the surface of the dead flat, and for its height the distance between the after dead flat, and the transverse division of the displacement into two equal parts, which is 1 7 (ft. in.).

Pl. 2. Fig. 1. & Pl. 3. Fig. 2. We have the ordinates prepared for finding the area of the portion of the dead flat between the upper and lower horizontal sections in MC. of Form 1: they amount to 234 ft., which must be multiplied by 3 ft. to find the area, and then by 1 ft. 7 in. to find the solid, or at once by 4 ft. 9 in. the product of these two quantities. This calculation in MC. of Form 2 gives 1111 ft. 6 in.

There is the other part of this same piece below the lower water line, also prismatic. Its base may be considered as a trapezium, having for one of its sides the breadth of the dead flat at the lower water line, and for another the breadth of the keel, and for its height 1 ft. 10.6 in. the distance from the lower water line to the rabbet. The height of the prism itself is 1 ft. 7 in. The result gives 36 ft. 8.10 in. to be added to the part above.

The calculation for the rest of the part below the lower water line, worked out in the same way, gives 615 ft. 5 in. more.

Lastly, the stern post and the part of the keel included in this half of the ship's bottom contain 188 cubic feet.

All these pieces combined give a total of 1448 tons 1379 lbs. as the displacement of the aftermost half of the immersed body.

It will be seen by a similar process in Form 3, that the displacement of the fore body is 1606 tons 208 lbs. There ought to be no difficulty in this calculation. The reader need only be reminded that the prism lying between the foremost dead flat, and the transverse division of the whole displacement is 10 ft. 5 in. in length.

The difference of capacity, therefore, is 157 tons 829 lbs.

that is to say, the displacement of the foremost half is that much in excess over the after. Pl. 2. Fig. 1. & Pl. 3. Fig. 2.

Adding together the displacements of these two halves, we have a total displacement of 3054 tons 1587 lbs. shewing an excess of 2 tons 811 lbs. over the result of the first calculations in Form 1. This difference can only arise, and does, in fact, arise from the difference of arrangement in the calculations for the small piece below the lower water line. In the first calculation it is treated as a paraboloid; and, moreover, we neglected a small piece of it between the two dead flats, as we only took into our account the general distance between the vertical sections = 10 ft. 1 in., whereas it is actually 12 ft. at that part: this omission alone gives 1 ton 1201 lbs. In the computation we have just gone through, the whole of this part between the two dead flats is treated as prismatic, which exposes a slight inaccuracy in the former supposition (viz. that it is a paraboloid). However, this is a difference which scarcely deserves notice: in calculations of this kind, for expedition's sake, it does not do to be over-scrupulous. In the following paragraph the calculation will present itself again in another shape, and some more trifling differences will be met with in the sum total.

Forms for the Calculation of Displacement in two equal parts.

FORM II.—*After Body.*

Ordinates.	1st. Sect.		2nd Sect.		3rd Sect.		4th Sect.		5th Sect.		6th Sect.		7th Sect.	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
7″	4	2	1	3.6		8		5		4.6		4.6		3.6
7	15	8	11	7	5	9	2	7	1	3.6		7		3.6
6	18	1.9	16	3	12	9	8	0.3	4	1	1	9.6		6.6
5	19	6	18	3.6	16	3.9	13		8	6.6	4		1	1
4	20	6	19	6.9	18	3.3	16		12	8	7	7	2	2
3	21	4.6	20	7.6	19	5.9	17	9.6	15	3.3	11	6	3	9.6
2	21	10.6	21	3.6	20	4.6	18	11	16	11	13	11.6	6	1.6
1	22	1.6	21	7.9	20	11.6	19	6	17	10	15	4	9	7
m.	22	2.6	21	10.6	21	2.6	20		18	4.6	16	0.6	11	9
	165	6.9	152	5	135	9.3	116	2.9	95	4.3	71	2	35	7.6
	5	3	4	6	3	9	3	4.6	3	4.6	3	4.6	3	4.6
	170	9.9	156	11	139	6.3	119	7.3	98	8.9	74	6.6	39	
	13	9.3	156	11	139	6.3	119	7.3	98	8.9	74	6.6	6	4.9
	157	0.6	313	10	279	0.6	239	2.6	197	5.6	149	1	32	7.3
	289	8	24	2	22	8.6	21	2	19	6	17	2	×10	1
	256	4												
	218	0.6	289	8	256	4	218	0.6	177	11.6	131	11	=328	9.1¼
	177	11.6												
	131	11												
	32	7.3												
	1263	6.9												
	×30	3												
	=38222	9.2¼												
AR.	65	11.5¼												
MC.	1111	6												
	36	6.10												
V.	616	5												
Q.	188													
	40241	4.6½												
	×72													
	=2897379													
	tons.	lbs.												
	= 1448	1379												

T.

2 9.6 80 8	83 5.6	85 0.6
12	1 7 10 5	
70 7 4 0.6	74 7.6	85 0.6
170 1	170 1	170 1

MC.

1 7 ×3	11 9 7.6
=4 9	12 4.6 ×1 10.6
234 ×4 9	= 23 2.5½ ×1 7
1111 6	= 36 8.10

V.

328	9.1¼
×1	10.6
=616	5.0

Forms for the Calculation of Displacement in two equal parts.

FORM III.—*Fore Body.*

Ordinates.	1st Sect.	2nd Sect.	3rd Sect.	4th Sect.	5th Sect.	6th Sect.	7th Sect.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
M.	22 2.6	21 11	21 2.6	20	18 4.6	16	11 9
I.	22 2.6	21 9.3	21	19 8	17 10	15 3.9	9 1.3
II.	22 2	21 7.6	20 7.9	19 0.6	16 11	14 1.6	5 4.6
III.	22	21 2.6	19 10	17 10	15 4.3	11 7	2 11
IV.	21 2	20 1	18 4.3	15 11	12 6.6	8 1	1 8.6
V.	19 7	18	15 8	12 7	8 9.6	4 5.6	11.6
VI.	15 10	13 9.6	10 8 6	7 1	3 10	1 6	5.6
VII.	6 9	4 5	2 1	4	4.6	4.6	3.6
	151 11	142 9.9	129 6	112 5.6	94 0.3	71 5.3	32 6.9
	4 8	4	3 4	3	3	3	3
	156 7	146 9.9	132 10	115 5.6	97 0.3	74 5.3	35 6.9
	14 5.9	146 9.9	132 10	115 5.6	97 0.3	74 5.3	6 4.9
	142 1.3	293 7.6	265 8	230 11	194 0.6	148 10.6	29 2
	266 3.6	27 4	24 1.6	21 1	19 6	17 1.6	×10 1
	241 6.6						
	209 10	266 3.6	241 6.6	209 10	174 6.6	131 9	=294 1.2
	174 6.6						
	131 9						
	29 2	MC.					V.
	1195 2.9	10 5	33 2.5¼				294 1.2
	× 30 3	×3	×10 5				× 1 10.6
	36155 8.2¼	=31 3	=241 8.4				=551 5.2¼
AV. . .	165 8.6						
MC. . {	7312 6	234					
	241 8.4	×31 3					
V. . .	551 5.2¼						
Q. . .	187	=7312 6					
	44614 0.2½						
	×72						
	=3212208						
	tons. lbs.						
=	1606 208						
	1448 1379	After body.					
	3054 1587						

III.

Method of finding the solid content of the immersed part in longitudinal divisions, for making a scale of displacement.

Pl. 2. Fig. 1. & Pl. 3. Fig. 3. We have seen in the first paragraph of this section, what these longitudinal divisions are, viz. divisions or slices of the ship's bottom contained between the planes of the water-lines. To find the solid content of each respectively, we have only to follow the principle laid down in that paragraph, one part of which alone comes into operation: that is to say, we have only to *multiply the area of the edge of the prism by the sum of quarter of the extreme, and half the other ordinates of the horizontal sections, which enclose the division.* There are no intermediate sections.

The following Form No. 4, contains seven columns, viz. six for the six divisions, and the last for the part below the lower water line. The ordinates having been prepared in Form 1, we content ourselves with taking the result ready at hand, taking care to employ only half that of the second column of this form for the first division: the other half is for the upper section of the second division, and is found consequently here at the head of the second column. A similar plan has been followed for the rest, which will be seen by comparing the two forms.

We have still to find the contents of

First. A piece of each division between the two dead

flats of $\overset{\text{ft.}}{1}.\ \overset{\text{in.}}{11}$, owing to the distance between them differing by that much from the common distance between the vertical sections. Pl. 2. Fig. 1. & Pl. 3. Fig. 3.

Secondly. The small pieces of the fore and after body, as well as those pieces of the stem and stern-post, contained between the water lines.

Thirdly. The pieces below the lower water line; and the keel.

First. Then, for the pieces between the two dead flats; we take, for instance for the first division, the ordinates of one of these dead flats in the first section, $\overset{\text{ft.}}{22}\ \overset{\text{in.}}{2.6}$, and in the second $\overset{\text{ft.}}{21}\ \overset{\text{in.}}{10.6}$: we add them together, increased by $\overset{\text{in.}}{7.}$ for the thickness of plank at the first section, and $\overset{\text{in.}}{6.}$ for the same at the second; and multiply the whole $\overset{\text{ft.}}{45}\ \overset{\text{in.}}{2.}$ by $\overset{\text{ft.}}{5}\ \overset{\text{in.}}{9}$, (the product of the length $\overset{\text{ft.}}{1}\ \overset{\text{in.}}{11}$. into the depth $\overset{\text{ft.}}{3}$) which gives a solid content of $\overset{\text{ft.}}{259}\ \overset{\text{in.}}{8.6}$, for the piece between the two dead flats, belonging to the first division. Those of the other divisions, set down on the line MC, Form 4, are obtained in the same way.

Secondly, with reference to the pieces of the fore and after bodies. Let us begin with the fore body: the one belonging to the first division may be treated as a truncated pyramid, having for one of its bases VII″o, VII‴ S 1, S (Pl. 2, Fig. 2,) and for the other VII″o, VII‴ S 2, S′: the distance from the ordinate to the bow at the first section VII″o S is $\overset{\text{ft.}}{4}$, at the second VII″o S′ $\overset{\text{ft.}}{3}$. We know from Geometry that, to find the contents of a frustum of a pyramid, we must find that of the whole pyramid, and

Pl. 2. Fig. 1. & Pl. 3. Fig. 3. that of the part towards the apex which is cut off, and subtract one from the other; the remainder will be the solid content of the frustum. And as, to do this, it is necessary to have the height of the whole pyramid, we make use of the following proportion. The difference of the corresponding sides of the bases is to the height of the frustum, as the greater of these two corresponding sides is to the height sought. The frustum being given, the three first terms of this proportion are known.

This, however, is only a supposition; the piece whose solid content we are in search of, and which we are considering as a pyramid is not one exactly; and the corresponding sides are not proportional. VII″o S, is 4 ft. VII″o S′ is 3 ft.; but VII″o VII‴ S 1, including planking is $\overset{\text{ft.}}{7}\ \overset{\text{in.}}{4}$.; and VII″o VII‴ S 2, $\overset{\text{ft.}}{4}\ \overset{\text{in.}}{11}$.; no proportion subsists. To meet this difficulty we will apply the rule to each comparison, and then add them together and get the mean.

$$\text{1st.}\quad \overset{\text{ft.}}{7}\ \overset{\text{in.}}{4} - \overset{\text{ft.}}{4}\ \overset{\text{in.}}{11} = \overset{\text{ft.}}{2}\ \overset{\text{in.}}{5}\ :\ \overset{\text{ft.}}{3}\ ::\ \overset{\text{ft.}}{7}\ \overset{\text{in.}}{4}\ :\ x = 9.128$$

$$\text{2nd.}\quad \overset{\text{ft.}}{4} - \overset{\text{ft.}}{3} = \overset{\text{ft.}}{1}\ :\ \overset{\text{ft.}}{3}\ ::\ \overset{\text{ft.}}{4}\ :\ y = 12$$

Thus we have for the mean height of the whole pyramid, $\frac{9.128 + 12}{2} = 10.564$ or $\overset{\text{ft.}}{10}\ \overset{\text{in.}}{6.9}$: for that of the small pyramid at the apex, $\overset{\text{ft.}}{10}\ \overset{\text{in.}}{6.9} - \overset{\text{ft.}}{3} = \overset{\text{ft.}}{7}\ \overset{\text{in.}}{6.9}$; then finding the area of each of their bases, multiplying these areas by the third of each height respectively, viz. $\overset{\text{ft.}}{10}\ \overset{\text{in.}}{6.9}$ and $\overset{\text{ft.}}{7}\ \overset{\text{in.}}{6.9}$, and subtracting the lesser product from the greater, the remainder will be the solid content sought.

It is almost superfluous to mention that to get the areas

in question, we must add together in each case, the ordi- Pl. 2. Fig. 1. &
nate and the half breadth of the stem, and multiply the Pl. 3. Fig. 3.
sum by the distance between these two lines: for instance in the first case, area $= (\overset{\text{ft.}}{7}\ \overset{\text{in.}}{4} + \overset{\text{ft.}}{0}\ \overset{\text{in.}}{7.6}) \times \overset{\text{ft.}}{4}$, and the second in the same way.

These operations give us $\overset{\text{ft.}}{70}\ \overset{\text{in.}}{2.1}$ for the small piece belonging to the first division.

A similar process gives $\overset{\text{ft.}}{32}\ \overset{\text{in.}}{4.9}$ for the second.

That for the third and last, $\overset{\text{ft.}}{6}\ \overset{\text{in.}}{3}$ is more simple, because it is sufficiently pyramidal, the summit being in VII.

These three quantities are set down in the line AV of Form 4.

We will not stay long at the small pieces of the after body; the rake of the stern post not being very considerable, they may be treated as prismatic, by deducing a mean length from those of the upper and lower bases. We will take, therefore, for the piece belonging to the first division, the ordinate $\overset{\text{ft.}}{4}\ \overset{\text{in.}}{2}$ and $\overset{\text{in.}}{7}$ for the planking, $\overset{\text{in.}}{7\frac{1}{2}}$ for the half breadth at the stern post: the ordinate for the second section $\overset{\text{ft.}}{1}\ \overset{\text{in.}}{3.6}$, $\overset{\text{in.}}{6}$ for the planking, $\overset{\text{in.}}{7\frac{1}{2}}$ for the half-breadth of the stern post at that section; and multiply the sum of these quantities by the thickness 3 ft. and the mean distance from the ordinate to the stern post. For the first division, this distance is at the upper section $\overset{\text{ft.}}{2}\ \overset{\text{in.}}{9.6}$, at the second $\overset{\text{ft.}}{2}\ \overset{\text{in.}}{6.10}$. The mean therefore will be $\overset{\text{ft.}}{2}\ \overset{\text{in.}}{8.2}$.

The other divisions are disposed of in the same way,

Pl. 2. Fig. 1. & Pl. 3. Fig. 3

and the quantities $\overset{\text{ft.}}{31}\ \overset{\text{in.}}{9.9\frac{1}{2}}$, $\overset{\text{ft.}}{15}\ \overset{\text{in.}}{2.6\frac{3}{8}}$, &c. set down on the line A.R.

The parts of the stem and stern post, at the end of each division are $\overset{\text{ft.}}{3}$ in height, $\overset{\text{in.}}{15.}$ in width across, $\overset{\text{in.}}{18.}$ in mean depth fore and aft; which produce $\overset{\text{ft.}}{11}\ \overset{\text{in.}}{3}$, solid content for these two parts in each division: to be carried into the account.

Thirdly. The part of the bottom near the keel, is $\overset{\text{ft.}}{1397}\ \overset{\text{in.}}{1.1\frac{1}{2}}$, as is seen in the computation of V in Form 1; to which must be added the solid contents of the keel $\overset{\text{ft.}}{155}$ in length, $\overset{\text{in.}}{15}$ broad, and $\overset{\text{in.}}{18}$ deep (including the false keel) $= \overset{\text{ft.}}{290}\ \overset{\text{in.}}{7.6}$.

Recapitulating the solid contents of the several divisions, the whole displacement is found to be $\overset{\text{ft.}}{84728}\ \overset{\text{in.}}{2.1\frac{1}{6}}$ or $\overset{\text{tons.}}{3050}\ \overset{\text{lbs.}}{148\frac{1}{2}}$. As was foreseen in the second paragraph of this Chapter, a slight difference is found here from the displacement in Form 1, which exceeds the result just obtained by $\overset{\text{tons.}}{2}\ \overset{\text{lbs.}}{628}$. This difference arises from our having calculated the small pieces of the fore body with greater accuracy. There is no doubt that in ships built sharp at their extremities, the supposition that these small pieces are paraboloids, gives too great a displacement; but the supposition that they are conical would on the other side give too little; this would perhaps after all be better. However, as has been said before, it is not worth while spending any time upon such minutiæ.

FORM IV.—*Calculation of Displacement by longitudinal divisions.*

Division.		2nd Division.		3rd Division.		4th Division.		5th Division.		6th Division.		Floor and Keel.	
ft.	*in.*	*ft.*	*in.*	*ft.*	*in.*	*ft.*	*in.*	*ft.*	*in.*	*ft.*	*in.*	*ft.*	*in.*
21.	4.3	300.	4.6	270.	6.9	234.	3.9	195.		148.	2.9	1397.	1.1½
00.	4.6	270.	6.9	234.	3.9	195.		148.	2.9	73.	10.9	Q 290.	7.6
21.	8.9	570.	11.3	504.	10.6	429.	3.9	343.	2.9	222.	1.6	1687.	8.7½
30.	3.	× 30.	3	× 30.	3	× 30.	3	× 30.	3	× 30.	3	6900.	9.1½
												10603.	5.0⅜
07.	3.8¼	17270.	10.3¾	15272.	5.7½	12986.	8.5¼	10382.	8.2¼	6719.	3.4½	13231.	4.3¼
259.	8.6	253.		241.	6	224.	11.7½	202.	2.6	164.	1.4½	15541.	11.5
												17582.	8.7¼
67.	0.2¼	17523.	10.3¾	15513.	11.7½	13211.	8.0¾	10584.	10.8¼	6883.	4.9	19180.	3.0¾
70.	2.1	32.	4.9	6.	3								
31.	9.9½	15.	2.6½	10.	5.9½	8.	5.2½	7.	3.4⅛	6.	1.4½	84728.	2.1⅝
SP	11.3.	11.	3	11.	3	11.	3	11.	3.	11.	3		
												tons.	lbs.
30.	3.0¾	17582.	8.7¼	15541.	11.5	13231.	4.3¼	10603.	5.0⅜	6900.	9.1½	=3050	428

On the Scale of Displacement.

From one of the angles of a rectangular parallelogram, one of whose sides represents the quantity of displacement at the load water line, a curved line is drawn diagonally to the opposite angle, which line is the locus of all the displacements for the different draughts of water: this forms what is called the "scale of displacement," or "the ton scale."

To construct this figure, divide the line ED into equal parts, for a scale of tons: upon the perpendicular drawn upon E make scale of feet, ET: lay off upon ED a quantity of 3050 tons 428 lbs., for the displacement as found in the last form, and upon ET 21 ft. 4.6 in., the mean draught of water when the ship has this displacement. Draw the parallelogram CDET. Arrange a little Table, upon the Pl. 4.

Pl. 4. following plan, of all the displacements determined for the different draughts of water at each of the longitudinal sections which comprise the divisions that we have been calculating in Form 4.

FORM V.—*Table of Sectional Displacements for constructing the Ton Scale.*

In Cubic Feet.		In Tons.		Draught of Water.	
ft.	*in.*	*tons.*	*lbs.*	*ft.*	*in.*
290.	7.6	10.	925	1.	6
1397.	$1.1\frac{1}{2}$	50.	$590\frac{1}{2}$	1.	10.6
1687.	$8.7\frac{1}{2}$	60.	$1515\frac{1}{2}$	3.	4.6
6900.	$9.1\frac{1}{2}$	248.	$854\frac{1}{2}$	3.	
8588.	5.9	309.	370	6.	4.6
10603.	$5\ 0\frac{3}{8}$	381.	$1446\frac{1}{2}$	3.	
19191.	$10.9\frac{3}{8}$	690.	$1816\frac{1}{2}$	9.	4.6
13231.	$4.3\frac{1}{4}$	476.	$657\frac{1}{2}$	3.	
32423.	$3.0\frac{5}{8}$	1167.	474	12.	4.6
15541.	11.5	559.	$1020\frac{1}{2}$	3.	
47965.	$2.5\frac{3}{8}$	1726.	$1494\frac{1}{2}$	15.	4.6
17582.	$8.7\frac{1}{4}$	632.	$1955\frac{1}{2}$	3.	
65547.	$11.0\frac{7}{8}$	2359.	1450	18.	4.6
19180.	$3.0\frac{3}{4}$	690.	978	3.	
84728.	$2.1\frac{5}{8}$	3050.	428	21.	4.6

Pl. 4. Lay off upon ED the quantity E*e* of the displacement of the keel = 290 ft. 7.6 in., or 10 tons 925 lbs., and upon ET the draught of water EQ for that displacement, or the height of the keel and false keel at the lower edge of the rabbet = 18 in. Draw the parallelogram eEQ*q*, and you have a point *q*.

Upon ED lay off EF = 60 tons 1515½ lbs. of displacement for the keel and floor, and upon ET lay off E*f* for the

draught of water at the seventh or lower horizontal section which bounds this displacement. Draw the parallelogram FEf7, and you have the point 7. Pl. 4.

Proceed to lay off successively upon ED the displacement at the height of each of the other six horizontal sections 309 tons 370 lbs., 690 tons 1816½ lbs. &c. and upon ET the respective draughts of water at those displacements 6 ft. 4.6 in., 9 ft. 4.6 in. &c. drawing the corresponding parallelograms, and thus you will get the points 6, 5, 4, 3, 2: the point of the first or upper horizontal section is C.

Through all the points E, q, 7, 6, &c. C. draw a regular curve, and the scale of displacement is constructed. The use of this scale for finding the displacement at each draught of water, and the draught of water at each displacement may be easily understood. The draught of water for the displacement having been found, lay off the draught of water upon the scale of feet: through the point thus found draw a line parallel to ED; from the point where this parallel cuts the curve drop a perpendicular upon this same line ED. The point where this perpendicular falls will denote the displacement. To find the draught of water for a given displacement, the operation is reversed.

CHAPTER II.

On Hydrostatic Stability.

A floating body, as we have before observed, tends, by its weight, to sink into the fluid; and the pressure of the fluid on the part which is immersed tends again to raise the body: this may readily be proved by using the hand, instead of a weight, for pressing a vessel down in the water. The body will offer resistance in proportion as it is pressed down, and will acquire a gradually increasing power to rise, as soon as it is set free. The amount of this power depends upon the quantity of displacement; the subject we have just been discussing. The question now before us has reference to the equilibrium of the body.

Considering the body in a state of rest, and acted on by these two forces (viz. weight and pressure of water,) the resultant of each of them passes through the centre of gravity of system; otherwise according to the laws of mechanics, the body instead of remaining in its position would turn round. (See No. 322 de la Mechanique de Bezout.)

Another principle of mechanics, is that the resultant of the pressure or vertical force of the fluid passes through the centre of gravity of that part of the body which is immersed. (Ibid. No. 345.) This resultant is necessarily a vertical force, for the horizontal forces destroy one another.

A ship floating on the water does not remain in a state of such absolute rest, but that its equilibrium is often disturbed: the agitation of the fluid itself, the motions of weights on board make constant changes in it, and the hydrostatic stability of a ship consists in the resistance which it opposes to these changes of position or inclination.

The ship ABCD in a state of perfect rest, immersed in the water by her weight to the line AC, experiences an upward pressure in the direction BD, passing through the centre of gravity G, of her immersed part, and resisting the effect of her weight whose resultant is also BD. Her centre of gravity of system is also in this line BD.* Pl. 5. Fig 1.

If any agitation of the water, or other external cause, destroys this state of equilibrium, and gives her a little inclination, so that *a* B *e* becomes the immersed part: then another centre of gravity *g* obtains through which a new vertical force *g d* passes, which cuts the line BD, (where the centre of gravity of system has remained) in a certain point *m*.

If the centre of gravity of system is identical with this point, the vertical pressure tends neither to incline the vessel more nor to right her. If the centre of gravity is

* The "centre of gravity of displacement," means the centre of gravity of the immersed part of the hull, viewed as a body of uniform density, of whatever substance, whether wood or water.

The "centre of gravity of system," is the common centre of gravity of all the weights of the ship, whether the materials of her construction, her armament, rigging, &c. In a ship at rest, whose position is the effect of the disposition of the weights on board, and which is not acted on by any external cause, such as the wind, the "centre of gravity of system," is always vertical to the "centre of gravity of displacement." (Ed.)

Pl. 5. Fig. I. lower, in the point C for instance, the force exerted by the gravity, passing through this point C, combines with the opposite force passing through g to right the vessel. If on the contrary the centre of gravity is higher, as in c; a like combination of the gravity and upward pressure will take place, but its results will be fatal, for it will upset her.

It is of the first importance therefore that the point m, which M. Bonguer has called the metacentre, should be known, as well as the centre of gravity of system.

Analysis has furnished us with the formula $\frac{2}{3}\,\underline{\int y^{3}\,dx}$ (Traité du Navire, Par. 4, Chap. 3, Sect. 2, Liv. 2,) which enables us to determine the position of the metacentre, with reference to the centre of gravity of displacement. The following explanation will make it intelligible to those readers who are not acquainted with differential calculus. The distance of the metacentre from the centre of gravity of displacement is equal to *two-thirds of an area whose ordinates, for the same abscisses as the load water section, would be the ordinates of that section raised to the third power: this area being divided by the displacement.*

We are therefore going to calculate that distance by this method; afterwards, as we shall have determined nothing without the height of the centre of gravity of displacement, we will compute that also. Lastly, we will shew how the centre of gravity of the system, or of the whole vessel, is obtained. It is a computation whose elements are drawn, not only from the hull, but also from the guns, stores and rigging of the ship.

I

On the Computation of the Metacentre.

According to the rule we have just given, we have simply to calculate the area of the load-water section, but employing the cubes of its ordinates instead of the ordinates themselves. We then divide by the displacement, and take two-thirds of the product. The following is the form for this operation.

FORM VI.—*The Calculation of the Distance of the Metacentre from the Centre of Gravity of Displacement.*

Ordinates of the load-water sections, with thickness of plank.		The same in decimals.	Cubes of the Ordinates.	
	ft. in.			
7″	4 6	4·75	107·17	M.C.
7	16 3	16·25	4291·02	11836·76
6	18 8.9	18·72	6560·21	× 1·11
5	20 1	20·08	8096·38	
4	21 1	21·08	9367·24	= 22687·12
3	21 11.6	21·96	10590·02	
2	22 5.6	22·45	11314·86	
1.	22 8.6	22·70	11697·08	AR
m	22 9.6	22·79	11836·76	107·17
M	22 9.6	22·79	11836·76	0.25
I	22 9.6	22·79	11836·76	107·42
II	22 9	22·75	11774·55	
III	22 7	22·58	11512·56	53·71
IV	21 9	21·75	10289·11	× 2· 9· 6
V	20 2	20·16	8193·54	= 149·92
VI	16 5	16·41	4419·02	
VII″	7 4	7·33	393·83	AV
	327 4·9	327·34	144116·87	393·83
				0·25
				394·08
				197·04
				× 4·16
				= 796·37

144116·87

$\frac{107·17 + 393·83}{2} = 250·50$

143866·37

× 10·1

1450652·56

MC 22687·12

AR 149·92

AV 796·37

1474285·97

$$\frac{\frac{2}{3}\int y^3 dx}{D} = \frac{\frac{2}{3}\ 1474285}{84728} = 11·6 = 11 \text{ ft. } 7·3 \text{ in.}$$

The first column of this Form contains the ordinates of the load-water section, with the addition of 7 in. thickness of plank to each. In the second column we have these same ordinates, but expressed in decimals, to facilitate the computation. Lastly, the cubes of these ordinates form the third column; and they are considered as linear quantities, ordinates of the plane whose area we want to find. As we have seen before, only half the extreme ordinates are to be employed; so that we have to subtract from the sum of these cubes, the half of 107.17, and 393.83 or 250,50: multiplying the remainder by 10 ft. 1 in., the distance between the ordinates, we have the area sought, with the exception of the small pieces between the dead flats, and those of the fore and after body. For that between the dead flats, the cube of the ordinates at the dead flat, 11836.76 is to be multiplied by the distance 1 ft. 11 in., which is done in MC. For the small piece of the after body, half the sum of the ordinate, and half-breadth of stern-post cubed is multiplied by the length of this piece, viz. 2 ft. 9.6 in., and the same with the small piece of the fore body. All these quantities are then added together, and two-thirds of their sum is divided by the displacement 84728. The quotient 11 ft. 7.3 in. is the distance between the metacentre and the centre of gravity of displacement. The position of this last point has yet to be ascertained.

II.

On the Computation of the Centre of Gravity of Displacement.

The centre of gravity of displacement, the vessel being upright, is necessarily in the vertical-longitudinal plane, which divides the ship into two parts equal and alike.

To find its distance from a given vertical line in this longitudinal place, for instance the perpendicular of the stern post, we must find the centre of gravity of each of the horizontal sections relatively to this line, according to the method about to be shewn; make a sum of their moments, and divide that sum by the sum of these sections.

Lastly, to get its distance from a horizontal plane, such for instance as the load-water section, we must consider the areas of the horizontal sections, or planes of the water lines as linear quantities: and thus we view the volume of the ship's bottom as a plane, whose centre of gravity is to be sought in the way about to be shewn.

M. Bezout, who investigated the problem analytically, gives this rule for finding the distance of the centre of gravity of a plane of floatation from one of its extreme ordinates. 1*st*. *Add together the following quantities: one-sixth of this ordinate; one-sixth of the ordinate at the other extremity (this latter being multiplied by three times the number of the ordinates* — 4) *; the second ordinate (reckoning that as the first to which the centre of gravity is referred) ; double the third ; three times the fourth ; and so on with the rest.* 2*ndly*. *To half the extreme ordinates add*

all the intermediate ones. 3rdly. Divide the first sum by the second, and multiply the quotient by the space between the ordinates. This space should of course be constant, i.e. the distance between the ordinates should be equal.

This rule enables us to get the position of the centre of gravity of displacement with reference to one of the perpendiculars of the stem or stern post; which we are obliged to do in order to determine it absolutely, in case, for instance, of wishing to place it on the draft: but as its height is that which concerns us most at present, we will be content with ascertaining its distance from the plane of the load-water line. By taking this distance from 11 ft. 7.3 in. found as that between the metacentre and centre of gravity, we shall have the height of the said metacentre with reference to the load-water section. Our method of doing this will serve also as a guide for determining this point, if desired, with reference to one of the perpendiculars.

FORM VII.—*On the Height of the Centre of Gravity of Displacement.*

FIRST PART OF THE CALCULATION.		
Planes of floatation as ordinates.	Factors.	
321 4.3	× $\frac{1}{6}$	53 6.8
300 4.6	× 1	300 4.6
270 6.9	× 2	541 1.6
234 3.9	× 3	702 11.3
195	× 4	780
148 2 9	× 5	741 1.9
73 10.9	× $\frac{1}{6}$ × (21—4)	209 4.5½
1543 8.9 197 7.6		3328 6.1½
1346 1.3	$3.\ \frac{3328\ \ 6.1\frac{1}{2}}{1346\ \ 1.3} = \overset{\text{ft.}}{7}\ \overset{\text{in.}}{5}$	

SECOND PART OF THE CALCULATION.

Pieces of the "Carene."			Distance of their centre of gravity from load-water section.		Moments.
	81439	3.7½			
MC .	1345	6			
	82784	9.7½	× 7	5	613987.26
AR .	65	11.5¼	× 5		329.75
AV .	165	8.6	× 2	3	372.825
V. .	1397	1.1½	× 18	5.7	25797.654
Q 375 { St.Pt.	37	5	× 10		374.16
Stem	47		× 12	6	58.75
Keel	290	7	× 20	7.6	5993.21
	84788	6.8¼			646913.609

$$\frac{646913 \quad 6}{84788 \quad 6.8} = \overset{\text{ft. in.}}{7 \ 7.3}$$

In the first part of the above calculation we have exactly followed the method prescribed; we have in the first column the seven planes of floatation, or horizontal sections transferred from Form 1. It is true that we have here only set down the halves of those sections, and that we have omitted multiplying them by the distance between the ordinates 10 ft. 1 in.: but, as in the fraction below, these factors 2 and 10 ft. 1 in. would be common to both terms, they are left out. There is another observation to be made on the subject of the greater distance between the two dead flats, to which we shall come presently.

In the third column, where the horizontal sections, considered as ordinates, are prepared as directed, and whence the dividend is derived, the extreme ordinates are used entire; but we only want their halves in the divisor: this is the reason why 197 7.6 the half of the said extremes is subtracted from the total of the ordinates in the first

column. After dividing, the quotient is multiplied by 3 = the distance between the horizontal sections.

These operations give the distance of the centre of gravity of the main portion of the displacement from the load-water section; disregarding the small piece 1 ft. 11 in. in length between the two dead flats. But the value of this little quantity, if it were equally divided among the vertical divisions, would have no appreciable influence on this distance of the centre of gravity, which we adopt therefore as that of the principal portion of the displacement.

So, in the second part of the calculation we multiply this main portion, including the contents of the piece MC, by 7 ft. 5 in. the distance of its centre of gravity from the upper plane of floatation, to obtain the moment. The moments of the other pieces must be obtained in order to make a sum of the whole, which is to be divided by the total displacement, in order to get the distance of the centre of gravity of displacement from the upper plane. All these little pieces are collected from Form 1. To find their moments it is necessary first to determine the centre of gravity of each of these pieces; but in consideration of their insignificant dimensions, we may be satisfied with assuming their centres of gravity as in relation to some regularly formed geometrical body. The cone seems to resemble most of them nearest; but, as has been said elsewhere, any inaccuracy of this kind is of very secondary consideration.

We assume, therefore, the small pieces of the fore and after bodies to be cones, whose base is in the load-water

section; their centre of gravity therefore is at one-fourth of their height, i.e. (the cones being inverted,) at one-fourth of the distance from the load-water section to the rabbet of the keel. The piece abaft is about 20 feet (the draught of water exclusive of the keel) which gives 5 feet as the distance of its centre of gravity from the load-water section. That of the fore-body which terminates at the stem is 9 feet high: its distance therefore is 2 ft. 3 in.

The small piece of the floor is 1 ft. 10 in. high, as we see in Form I. Its centre of gravity consequently is 5.7½ in. from its base, which is the lower horizontal section; this section is 18 feet from the load-water section: thus this centre of gravity is altogether 18 ft. 5.7½ in. from the load-water line.

The piece marked Q includes the stem of 47 feet, the stern-post of 37 ft. 5 in. and the keel of 290 ft. 7 in. The height of the centres of gravity of the two former are respectively half their heights from the keel; that of the stem therefore is 12 ft. 6 in. and that of the stern-post 10 ft. from the load-water line. The distance of the centre of gravity of the keel from the rabbet, (inclusive of the false keel) is 9 in.; which, added to 1 ft. 10.6 in. the height of the lower piece of the floor, and 18 feet, that of the main portion of the displacement, gives 20 ft. 7.6 in. for its distance from the load-water section.

By means of all these distances we have the moments which form the third column. We have now only to divide the sum 646913.6 by the displacement 84788 ft. 6.8 in. to get the distance of its centre of gravity from the load-water section. This distance is 7 ft. 7.3 in., which, sub-

tracted from 11 ft. 7.3 in. the distance from the centre of gravity to the metacentre, leaves 4 ft. for the height of the metacentre above the load-water section. There remains to find where the centre of gravity of system of the whole vessel is situated relatively to this plane of floatation.

III.

On the Centre of Gravity of the System of the Ship fully equipped.

With the theory which we have just been applying we only want, in order to ascertain this point, to have a practical knowledge of the dimensions, position, &c. of all the parts which enter into the construction, the furniture, the armament, and the rigging of the ship, so that we may find their respective centres of gravity and moments relatively to three planes intersecting each other at right angles: viz. a horizontal plane, a vertical-longitudinal plane, and a vertical-transverse plane.

The first elements of Mechanics will be a guide for students who wish to undertake this calculation, which is a long one, but by no means a difficult one to those who are conversant with ships. It is a point of great importance in the design of a ship; but this is not the place to enter upon the discussion of it, as it has too much to do with details of equipment, stowage, armament, &c. The data for it may be found in works which especially treat of these subjects, and once that they have become familiar, patience alone is required to accomplish this laborious task.

SECTION SECOND.

OF A BODY OR SHIP FLOATING AND HAVING A PROGRESSIVE MOTION.

We have seen in Section I. how the water acts on the surface of the immersed parts of bodies floating in it. When these bodies have a progressive motion in the fluid at rest, a new action of the fluid on the said bodies results from it; an action which tends to oppose their motion. Ordinarily the progressive motion of ships is occasioned by the wind, or the motion of another fluid, the air.

The science of Hydrodynamics, however, which treats of these effects, has not yet furnished us with anything satisfactory on the subject: this impulse of the wind which gives motion to the machine; this resistance of the water which produces equilibrium: we conceive their effects, we are aware of their existence, but to measure them we must have a better knowledge than we at present possess of the internal mechanism of fluids, of the play of their parts, of the action which those innumerable atoms of which they are composed exert upon one another: their shape, their mutual arrangement, their tenacity, on all these points we are at fault: the greatest geometricians, for want of facts, have imagined hypotheses, and upon this bad foundation

have built up theories which have proved more elegant than useful. This is now acknowledged. If the resistance that a vessel experiences from the fluid in her progressive motion, is nearly proportional to the squares of the velocity, it is at least doubtful that the perpendicular and direct resistances which several plane surfaces experience, when moved with the same velocity, are proportional to the extent of those surfaces; for observers have thought that a rectangle, exposed to the direct impulse of a fluid, opposed a greater resistance with its long side vertical, than with its short, the reason for which I think I see. The pressure from the fluid which a body at rest in it experiences, the force of which is in a ratio to the depth at which it acts, ought to be combined with the impulse which the body in motion receives. Again, it is doubtful whether the resistance of a plane to the direct impulse of a fluid is equal to the weight of a column of that fluid, whose base is equal to the surface struck, and whose height is that from which a body must fall to acquire the velocity with which the stroke is made. The resistances to the oblique impact do not diminish in the ratio of the squares of the angles of incidence. What is the law of this diminution? It is not known. So here is the old theory of resistance almost entirely sapped to its foundation. But although we have succeeded in overthrowing a dangerous edifice, we have failed to replace it.

Theory, therefore, is of little help to us in the question of resistance; and stability under sail, that which I call *hydrodynamic stability*, is in some measure mixed up with

it. So we are obliged to confine ourselves to giving an idea of the problem which relates to this kind of stability. As to the question of greater or less resistance, we see that it depends chiefly upon the greater or less volume of the ship's bottom, without being able to determine anything as to its shape. The smallest volume with the greatest area of canvas that the vessel can carry ought, it would seem, to attain the greatest velocity.

It is impossible to build vessels which will not heel over when close to the wind, or when the wind is at all across the line of keel, without departing from the usual form, which, without being perfect, is not so far from perfection as to warrant such a change. We must be satisfied with confining this inclination within such bounds as the exigency of the service, and the safety and convenience of navigation demand.

The lateral pressure of the wind, and the lateral resistance of the water, are the forces which produce the inclination of the vessel on her side: the only one which can be a subject of anxiety: let us therefore investigate the equilibrium of the vessel in her progressive motion with reference to these forces.

Owing to the inclination of every part of the surface of Pl. 5. Fig. 2.
the ship's bottom to a horizontal plane, the resultant of the resistance cannot be horizontal. It exerts itself in a direction which we will represent by Rr, and the impulse of the wind upon the sails resolves itself into a line perpendicular to their surface Ir.

These two forces which we consider in their resultant,

Pl. 5. Fig. 2. cross each other in r: representing the quantity of the resistance by rr', that of the impulse will be ri, the side of the parallelogram $rr'vi$, whose diagonal rv would be vertical; for the motion of the vessel being horizontal, the horizontal parts of these forces destroy one another, and all that remains of them is rv, the resultant of rr' and ri.

The vessel in this state of inclination, has her centre of gravity of displacement at c, through which passes the resultant of the vertical thrust of the fluid, which acts upon the metacentre M. Her centre of gravity of system, where the force of her weight acts, has remained constant at C.

Supposing the horizontal line Mm to be an inflexible rod without weight, at the point m of which the force rv is applied, (drawing from r to v): experiencing the force of the vertical thrust at its point M, acting in the same direction as rv; and that of the weight at μ in the opposite direction, that is to say downwards; then $P \times M\mu$ must, in order to produce equilibrium, $= rv \times m\,M$ (calling P the weight of the ship); or the weight of the ship, multiplied into the distance between the centre of gravity of system, and a vertical line passing through the centre of gravity of displacement, must be equal to the resultant of the impulse of the wind and the resistance, multiplied into its distance from this same vertical line, passing through the centre of gravity of displacement.

It is evident that we cannot make use of this theory until we have a better knowledge of that which relates to the resistance or impulse of fluids: but, in the mean

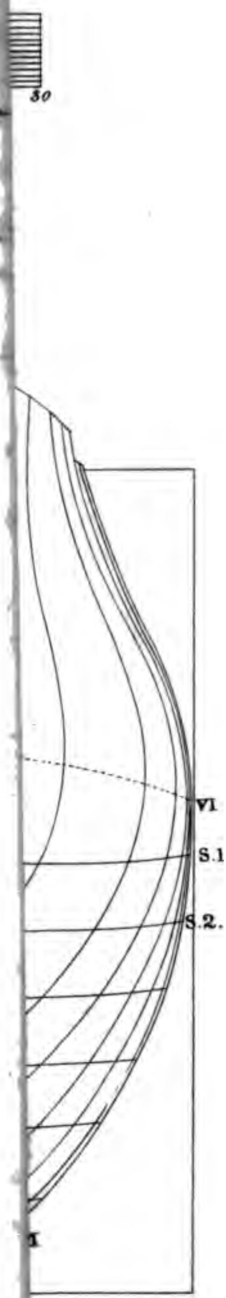
time, it serves to shew us that the positions of the metacentre, and of the centre of gravity of system are not sufficient for determining the stability under sail: it depends still on the inclination of Rr, and all M. Bouguer's attempts to simplify the question, have only enabled him to state that $ri \times zy = vr \times m$ M, $=$ P $\times$ μ M; that is to say, that the impulse of the wind upon the sails, multiplied by the distance of its resultant from the point of intersection of the resistance of the water Rr, with the vertical line passing through the centre of gravity of displacement cM; that this moment (I say) is equal to the weight of the vessel, multiplied by the distance of its centre of gravity of system, from this same vertical line, passing through the centre of gravity of displacement. He then thinks that this point of intersection, for the majority of vessels, may be supposed, without any appreciable error, to be in the metacentre; and in fact the distance at which it actually is from it cannot be very considerable, in proportion to the height of the centre of effort of the wind upon the sails: but we still require a measure of the impulse of the wind, for obtaining which we have not satisfactory data; and the use which may be made of what has just been said is rather, in my opinion, to teach us to recognize the force of this impulse. In fact, it is evident that all that is wanted for this investigation, besides the determination of the centres of gravity of the system, and of displacement, of the metacentre, and the quantity of inclination, is the area of those sails that are set, and the centre of impulse of the wind on those sails: which is

not difficult, considering the sails as planes. The result would give us the pressure of the wind at a given state of weather: which would be of use in estimating the stability for other conditions. These are suppositions whose legitimacy I will not guarantee, but when one is poor, one tries to make the most of every thing.

FINIS.

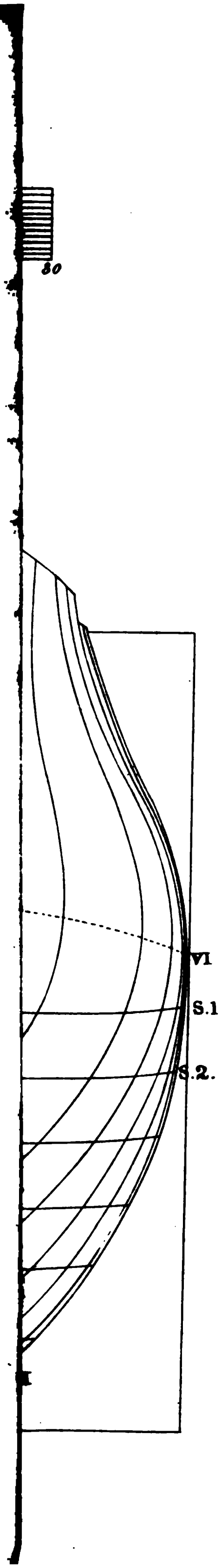
C. NORMAN, PRINTER, MAIDEN LANE, COVENT GARDEN.

Plate 1.



R. Martin, lith. 8, G^t Newport S^t

Plate 1.



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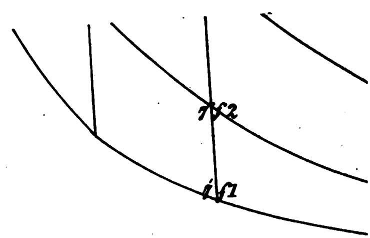
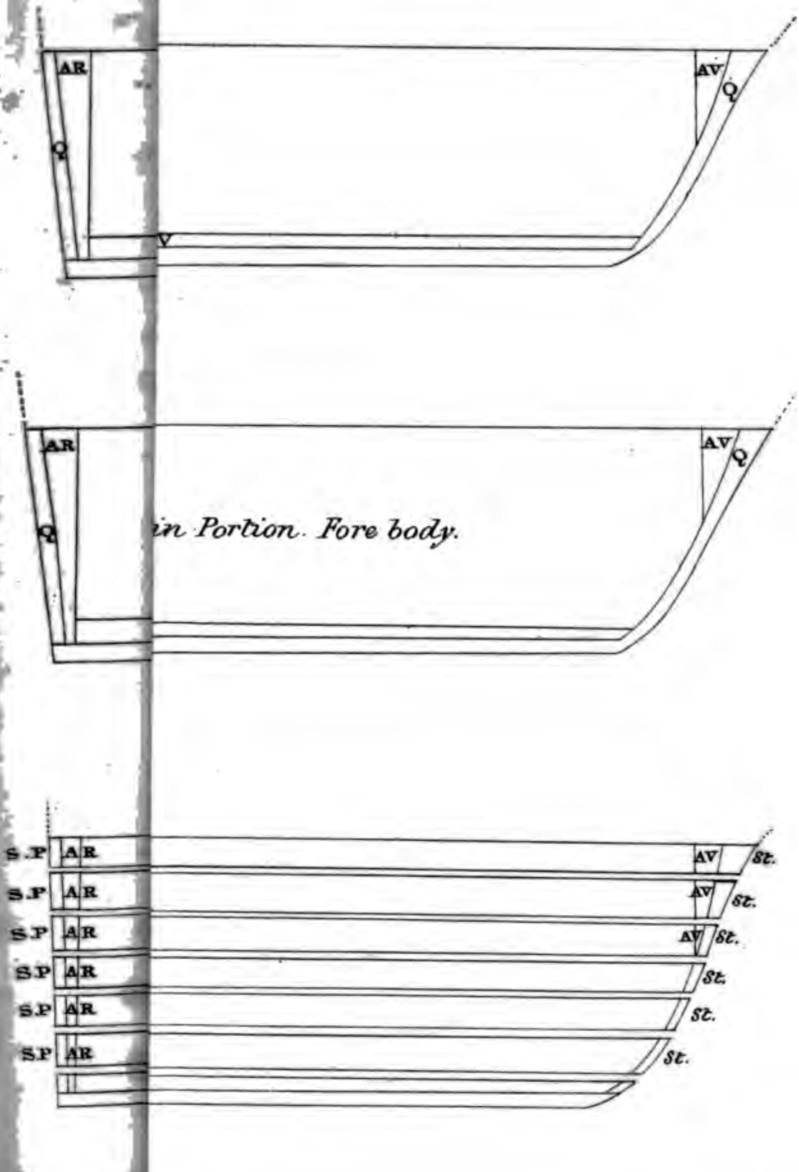


R. Martin, lith. 8, G^t Newport S^t

Plate 3.



R. Martin, lith. 8, Gt. Newport St.

Plate 4.

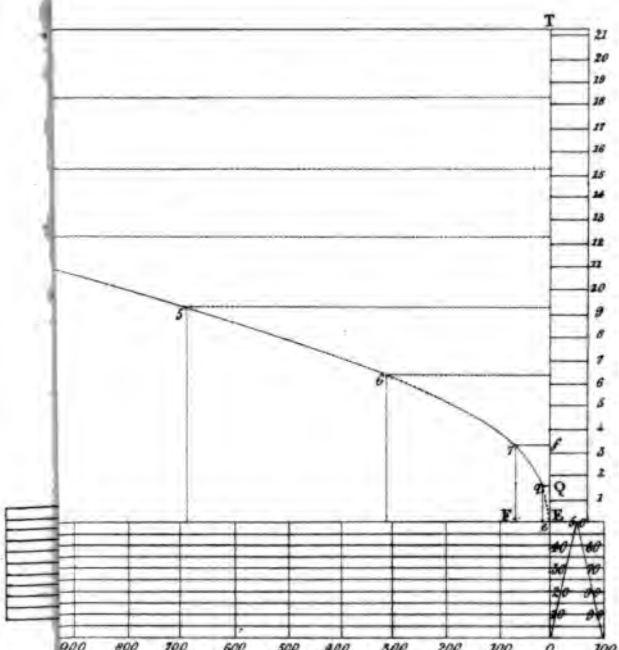


Plate 5.

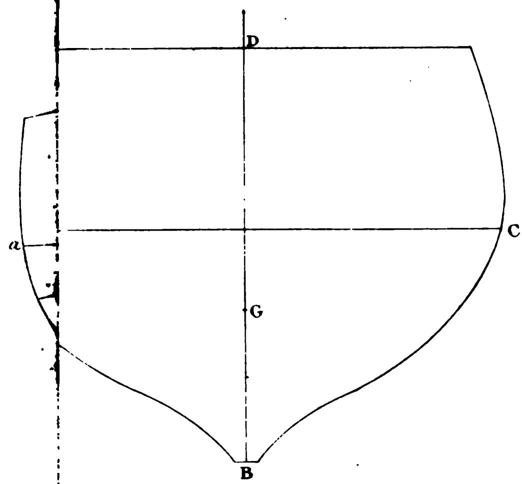


Fig. 3.